

## Krypton

**What Is It?** Krypton is a colorless, odorless, tasteless gas about three times heavier than air. It was discovered in 1898 by Sir William Ramsay and Morris Travers in the residue left after evaporating water, oxygen, nitrogen, helium, and argon from a sample of liquid air. The name comes from the Greek word *kryptos*, meaning hidden. As a noble gas, krypton is generally inert and forms very few chemical compounds. It occurs in nature as six stable isotopes. (Isotopes are different forms of an element that have the same number of protons in the nucleus but a different number of neutrons.) Krypton-84 is the most prevalent, comprising about 57% of natural krypton. The other five stable isotopes and their relative abundances are krypton-78 (0.4%), krypton-80 (2.3%), krypton-82 (12%), krypton-83 (11%), and krypton-86 (17%).

<b>Symbol:</b>	<b>Kr</b>
<b>Atomic Number:</b> (protons in nucleus)	<b>36</b>
<b>Atomic Weight:</b>	<b>84</b>

Eleven major radioactive isotopes of krypton exist of which only two – krypton-81 and krypton-85 – have half-lives long enough to warrant concern. Krypton-81 has a half-life of 210,000 years, and krypton-85 has a half-life of 11 years; the half-lives of the other krypton isotopes are less than two days. Krypton-85 is the isotope of concern at Department of Energy (DOE) environmental management sites such as Hanford. It is produced by the fissioning of uranium and plutonium and is present in spent nuclear fuel. The low specific activity of krypton-81 limits its radioactive hazards.

**Radioactive Properties of Key Krypton Isotopes**

Isotope	Half-Life (yr)	Specific Activity (Ci/g)	Decay Mode	Radiation Energy (MeV)		
				Alpha ( $\alpha$ )	Beta ( $\beta$ )	Gamma ( $\gamma$ )
<b>Kr-81</b>	210,000	0.021	EC	-	0.0051	0.012
<b>Kr-85</b>	11	400	$\beta$	-	0.25	0.0022

*EC = electron capture, Ci = curie, g = gram, and MeV = million electron volts; a dash means the entry is not applicable. (See the companion fact sheet on Radioactive Properties, Internal Distribution, and Risk Coefficients for an explanation of terms and interpretation of radiation energies.) Values are given to two significant figures.*

**Where Does It Come From?** Krypton is naturally present in meteorites and minerals in trace quantities. It exists naturally in the atmosphere at a concentration of about 1 cubic centimeter per cubic meter ( $\text{cm}^3/\text{m}^3$ ). Radioactive krypton-85 is present in the natural environment in minute quantities due to the spontaneous and neutron-induced fission of uranium and other actinides. Krypton-81 and krypton-85 are both present in the atmosphere due to neutron capture reactions from cosmic ray neutrons interacting with stable krypton isotopes. Krypton can be obtained as a byproduct from the liquefaction and separation of air.

The major source of krypton-85 is nuclear fission. When an atom of uranium-235 (or other fissile nuclide) fissions, it generally splits asymmetrically into two large fragments – fission products with mass numbers in the range of about 90 and 140 – and two or three neutrons. (The mass number is the sum of the number of protons and neutrons in the nucleus of the atom.) Krypton-85 is one such fission product with a fission yield of about 0.3%. That is, three atoms of krypton-85 are produced per 1,000 fissions. An estimated 5 million curies of krypton-85 were released to the atmosphere as a result of nuclear weapons tests from 1945 through 1962. A large commercial nuclear power plant produces about 300,000 curies of krypton-85 per year, essentially all of which is retained within the fuel elements. This gaseous radionuclide is a component of spent nuclear fuel and is generally released to the atmosphere when the fuel is reprocessed. About 50,000 curies of krypton-85 were released to the atmosphere as a result of the accident at Three Mile Island in which a large number of fuel elements ruptured.

**How Is It Used?** Krypton has a number of industrial and medical applications. It is used alone or in combination with argon and neon in fluorescent lights. It emits a characteristic bright orange-red color and is used in lights at airports because the red light is visible for long distances and penetrates fog and haze to a greater extent than ordinary light. Krypton is also used in tungsten-filament projection lamps for home movies and slide projectors. A krypton gas laser produces a very intense and concentrated light,

and these lasers are used for medical applications such as surgery on the retina of the eye. The intense krypton laser light causes the blood to clot during the surgery, thus preventing further bleeding with subsequent loss of vision, and the laser is so accurate that surrounding tissues are not damaged.

Krypton is also used as a standard because the spectral lines of its isotopes are very sharp. In 1960, the International Commission on Weights and Measures defined the length of the standard meter as exactly 1,650,763.73 wavelengths (in a vacuum) of the orange-red line in the emission spectrum of krypton-86. This unit was redefined in October 1983 as the path length of light in a vacuum during a time interval of  $1/299,792,458$  of a second. Radioactive krypton-85 is used to detect leaks from sealed containers, with the escaping atoms being identified through their radiation. Krypton-85 is also used to excite phosphors in light sources with no external source of energy and in medicine to detect abnormal heart openings.

**What's in the Environment?** The highest concentrations of krypton are in the atmosphere. Krypton is present in air at a concentration of about  $1 \text{ cm}^3/\text{m}^3$ , or parts per million by volume. On a mass basis, the concentration is about 3 mg/kg. For comparison, the krypton concentration in the atmosphere of Mars is about 1/3 this amount ( $0.3 \text{ cm}^3/\text{m}^3$ ). Krypton is naturally present in the earth's crust at a concentration of about 0.15 micrograms per kilogram ( $\mu\text{g}/\text{kg}$ ), and its concentration in seawater is about  $0.21 \mu\text{g}/\text{liter}$ . Krypton-85 has been released to the atmosphere during nuclear fuel reprocessing activities and as a result of past aboveground nuclear weapons tests. In 1970, the concentration of krypton-85 in the atmosphere reached about 10 picocuries ( $\text{pCi}/\text{m}^3$ ) (or 10 trillionths of a curie per  $\text{m}^3$ ), mainly from nuclear weapons tests and plutonium production activities. The concentration is significantly lower now due to the relatively short half-life of this radionuclide, the cessation of aboveground nuclear weapons tests in the early 1960s, and the shutdown of plutonium production facilities at DOE sites. Neither the oceans nor the land surfaces act as significant sinks for this radionuclide. The only significant source of krypton-85 at the Hanford Site is in stored spent nuclear fuel.



**What Happens to It in the Body?** As a noble gas, krypton does not generally participate in any biological processes. After being taken into the body, a very small amount can be dissolved in the bloodstream and distributed to organs and tissues throughout the body. Nevertheless, the tissue of most concern from exposure to a cloud of krypton-85 gas is generally the skin, with most of the dose resulting from the beta particles associated with its radioactive decay.

**What Are the Primary Health Effects?** The main health concern is the increased likelihood for cancer induction, and the exposure pathway of most concern is external exposure in a cloud of gas. The radiation dose for krypton-85 (the primary isotope of concern for DOE) from an external cloud of gas is more than 130 times higher than the dose from any gas in the lungs and more than 200 times higher than that from any gas in body organs and tissues after being taken into the body. For krypton-81, most of the dose is associated with gamma rays that will irradiate all tissues and organs of the body. In contrast, much of the dose for krypton-85 is from beta particles, and the skin is the primary tissue of concern.

**What Is the Risk?** Radiation doses from inhaling or ingesting krypton are small compared to the dose from external radiation, such as could occur in a cloud of krypton gas. In contrast to most other radionuclides, lifetime cancer mortality risk coefficients have not been developed for the inhalation and ingestion of krypton isotopes. The only pathway for which cancer mortality risk coefficients have been developed is external exposure. External gamma risk coefficients for krypton-81 and krypton-85 were used to estimate lifetime cancer mortality risks for submersion in krypton clouds. If it is assumed that krypton releases occurred and 100,000 people were continuously exposed to a cloud of air with an average concentration of  $1 \text{ pCi}/\text{cm}^3$  over a period of one year, then the estimated number of fatal cancers in this group of 100,000 would be 2 for krypton-81 and less than 1 for krypton-85. (This is in comparison to the 25,000 people from this group who would be predicted to die of cancer from all other causes per the U.S. average.) This risk is due to the beta particles and gamma rays associated with the two krypton isotopes. (For more information, see the companion fact sheet on Radioactive Properties, Internal Distribution, and Risk Coefficients and the accompanying Table 1.)